RHIC Spin Physics

- Long term goals of the program:
  - gluon contribution to proton spin (ΔG);
  - parity-violating W production;
  - pp elastic scattering
- Physics from RHIC run-2 polarized proton collisions
  - Unpolarized pp cross sections for heavy-ion reference;
  - Transverse single spin asymmetries (A_N) for local polarimetry;
  - Physics implications of large A_N in $p_{\uparrow}p$ collisions at $\sqrt{s}$=200 GeV
- Plans for physics during RHIC run-3 polarized proton collisions
  - Improve precision of A_N measurements;
  - First measurements of A_{LL} for jets and single particles $\Rightarrow$ progress towards ΔG

L.C. Bland
BNL
17 March 2003

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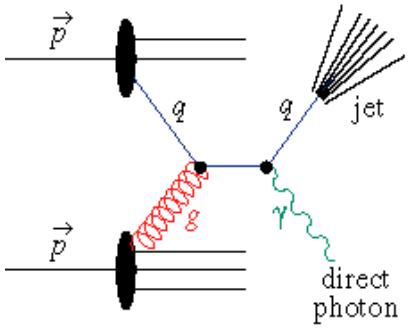
Gluon Contribution to the proton's spin

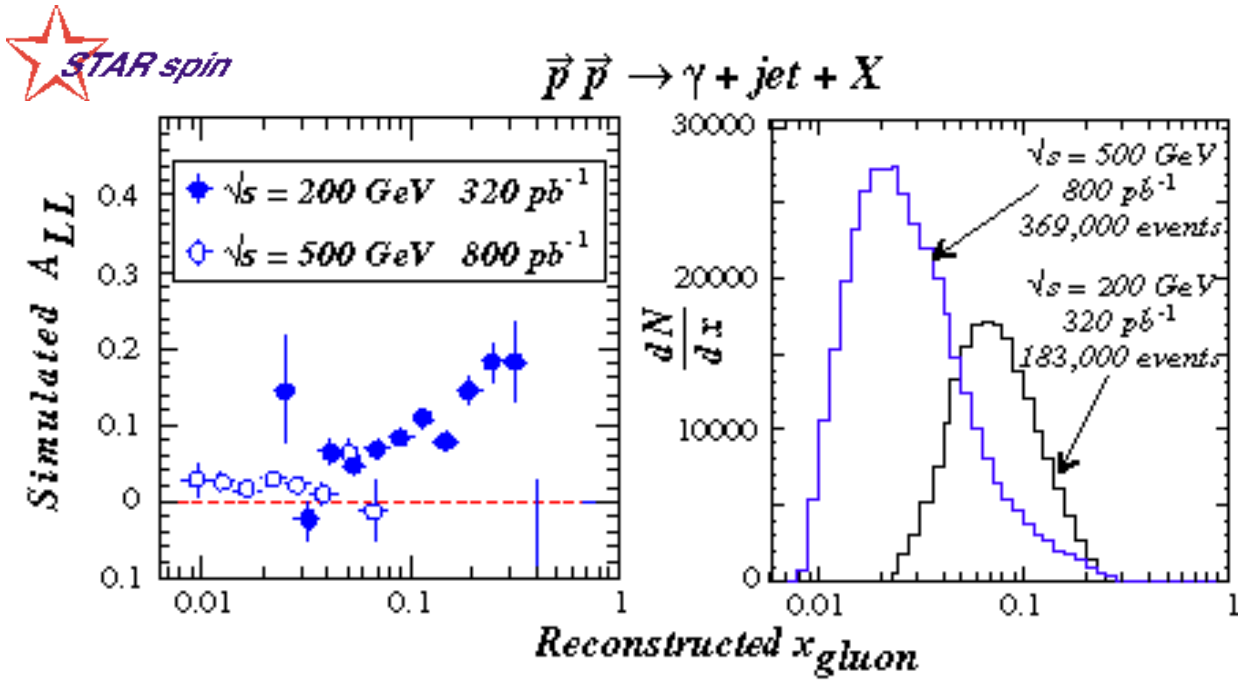
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$$\vec{p} + \vec{p} \rightarrow \gamma\,(+\,jet) + X$$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) *with longitudinally polarized protons*

$$P_{b1} P_{b2} A_{LL} = \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{b1(2)}$ — *beam pol'n* (~70%)

$N_{++(+-)}$ — *equal (opposite) helicity yield*

R — *relative luminosity*

Flavor Structure Sensitivity:

N. Bruner,UNM
SPIN2002

$$\vec{p}p \rightarrow W^{\pm}$$

for $x_1 >> x_2$ (larger y_W):

$$A_L^{W^+} \sim \frac{\Delta u(x_1)}{u(x_1)}$$

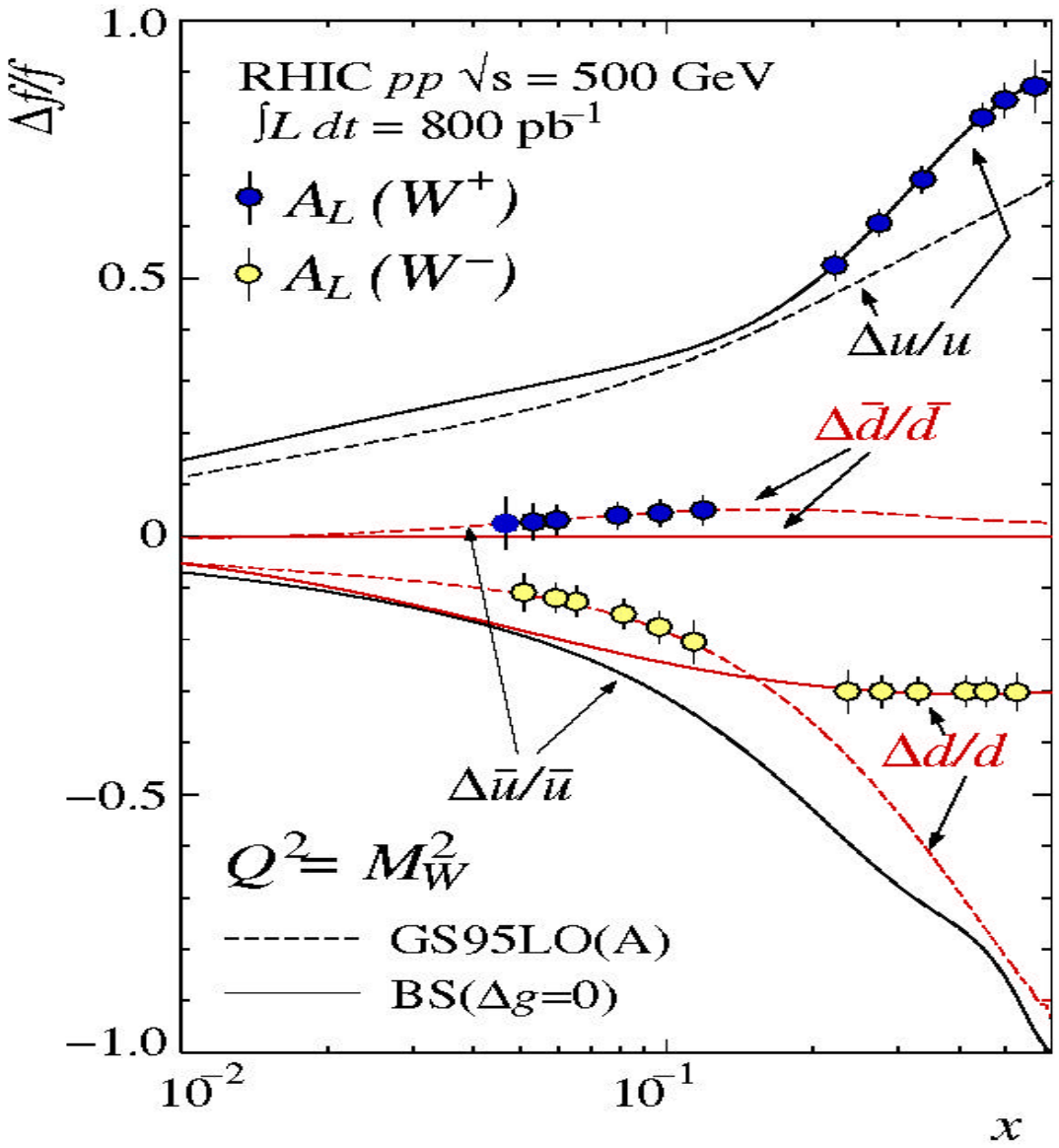
$$A_L^{W^-} \sim \frac{\Delta d(x_1)}{d(x_1)}$$

for $x_2 >> x_1$:

$$A_L^{W^+} \sim -\frac{\Delta \bar{d}(x_1)}{\bar{d}(x_1)}$$

$$A_L^{W^-} \sim -\frac{\Delta \bar{u}(x_1)}{\bar{u}(x_1)}$$

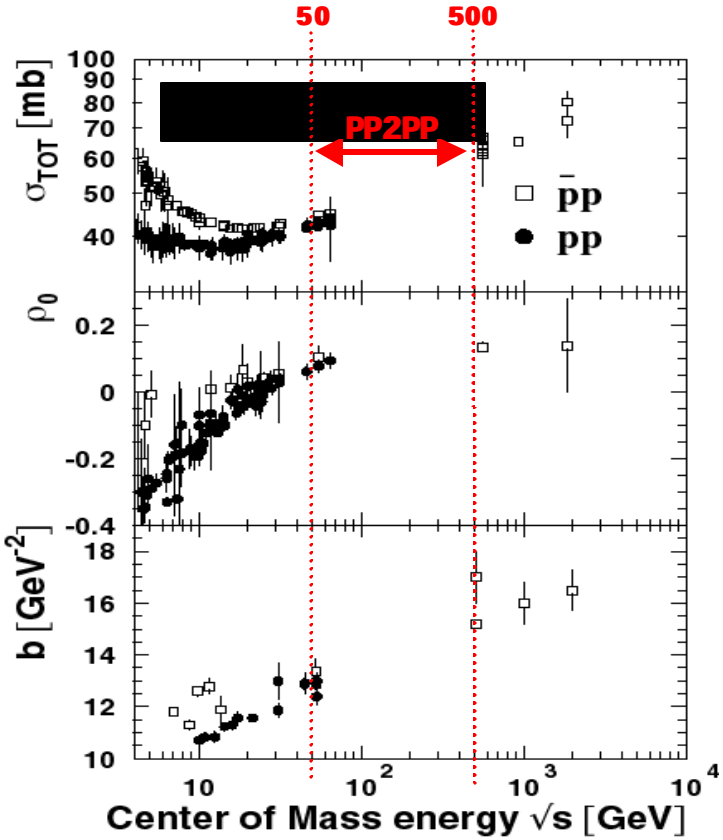
for explicit x and y_W see
C. Bourrely and J.Soffer,
Nucl. Phys. B445 341-379 (1995)



The pp2pp Experiment at RHIC

Measures elastically scattered protons in range of 50 GeV to 500 GeV c.m.s. energy, $\sqrt{s}$, in the four-momentum transfer range of $4 \cdot 10^{-4}\ \mathrm{GeV}^2 \lesssim |t| \lesssim 1.3\ \mathrm{GeV}^2$ (at $\sqrt{s}$ = 500 GeV), covering region of

- **Coulomb interaction for $|t| < 10^{-3}\ \mathrm{GeV}^2$**
  - Measure total cross section σ_{tot}
- **Hadronic interaction for $5 \cdot 10^{-3}\ \mathrm{GeV}^2 \lesssim |t| \lesssim 1\ \mathrm{GeV}^2$**
  - Measure forward diffraction cone slope **b**
- **Interference between Coulomb and hadronic interaction (CNI-region)**
  - Measure ratio of real and imaginary part of forward scattering amplitude r_0
- **Diffractive dip structure**
  - Measure possible Odderon contribution to spin exchange in region with previously observed sign change of single spin asymmetry



Physics from RHIC Run-2 $p_{\uparrow}p$ Collisions

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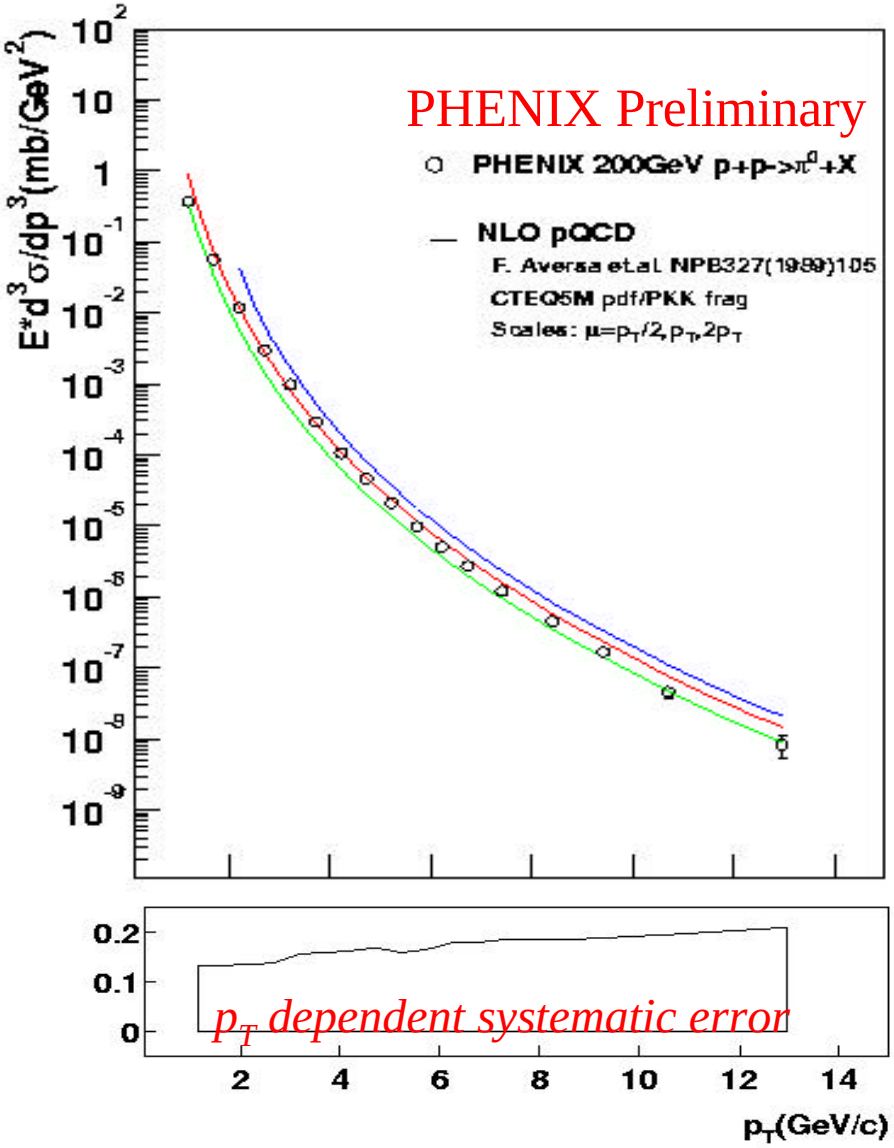
p^0 Cross Section

- The data covers over 8 orders of magnitude
  - –by combining minimum bias trigger and EMCal trigger data
- NLO pQCD calculation is consistent with our data
  - –CTEQ5M PDF + PKK FF
  - –within the scale $\mu = p_T/2 - 2p_T$

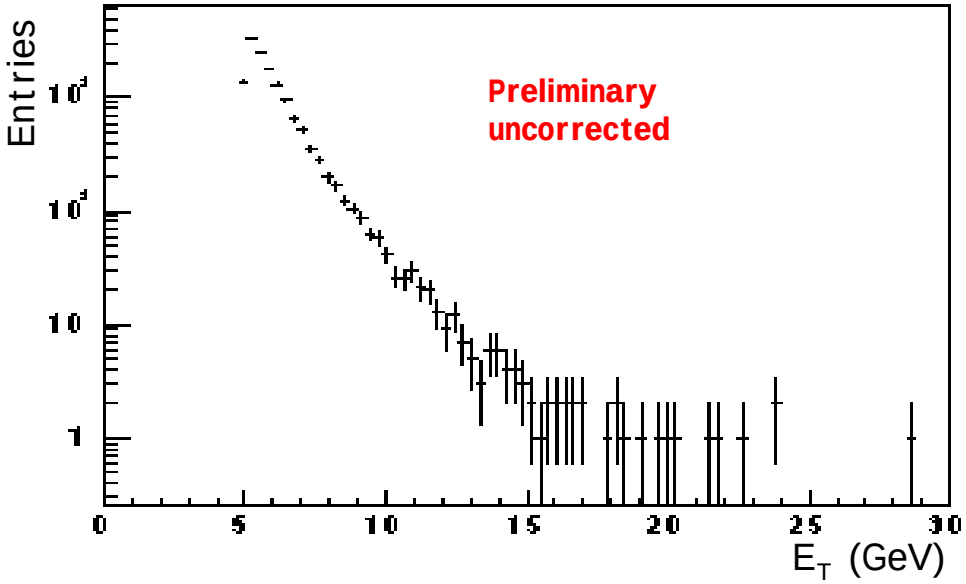


H. Torii, Kyoto University
B. Fox (RBRC), SPIN 2002

normalization systematic error 30% is not included

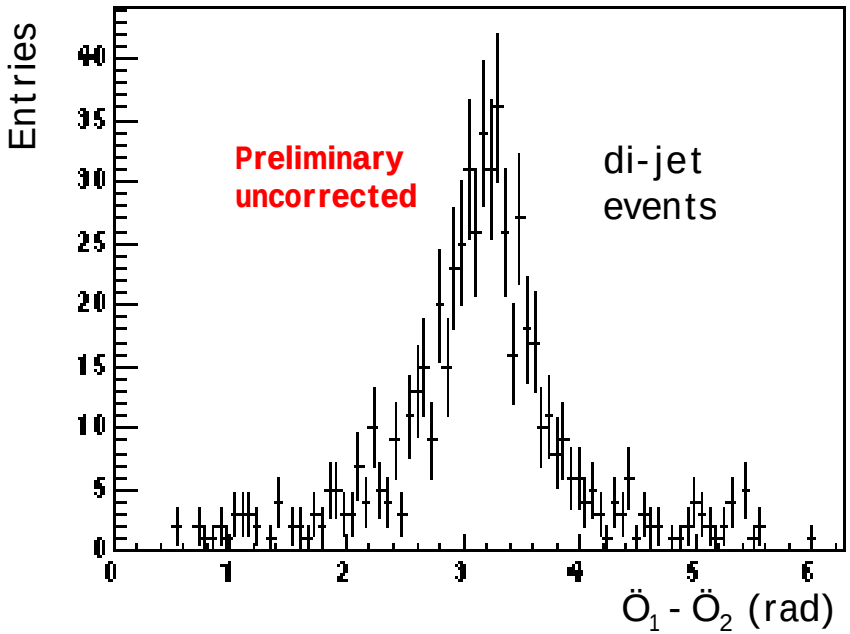
Status of Run 2 jet analysis

- Very first "look" at jets:
  - DATA: STAR minimum-bias pp data: $\sqrt{s}$ = 200 GeV
  - Jet algorithm: Cone jet Finder for charged particles only: R = 0.7, seed > 1 GeV, E_T > 5 GeV, $|\eta^{jet}| < 0.7$
  - Quantitative comparison to MC simulations (e.g. Pythia) requires detailed studies of detector efficiencies



NOTE: Realistic simulations to account for detector efficiencies are required!

First "look" to "see" jets is encouraging in view of our spin program ("inclusive jets") in FY03!



Engineering Run of 2002

Conditions

14 hour run with high â* = 10 m beam tune

beam momentum *p* = 100 GeV/*c*

55 proton bunches per beam

beam scraped to emittance å » 12 ð •10^{-6} m

and beam intensity *I* £ 5•10^{11} protons

beam polarization *P* = 0.24 (preliminary)

Closest approach of first detector strip to beam

15 mm » 15 s_{beam} ® t_{min} = -4•10^{-3} GeV^2

Collected ~300,000 elastic scattering events

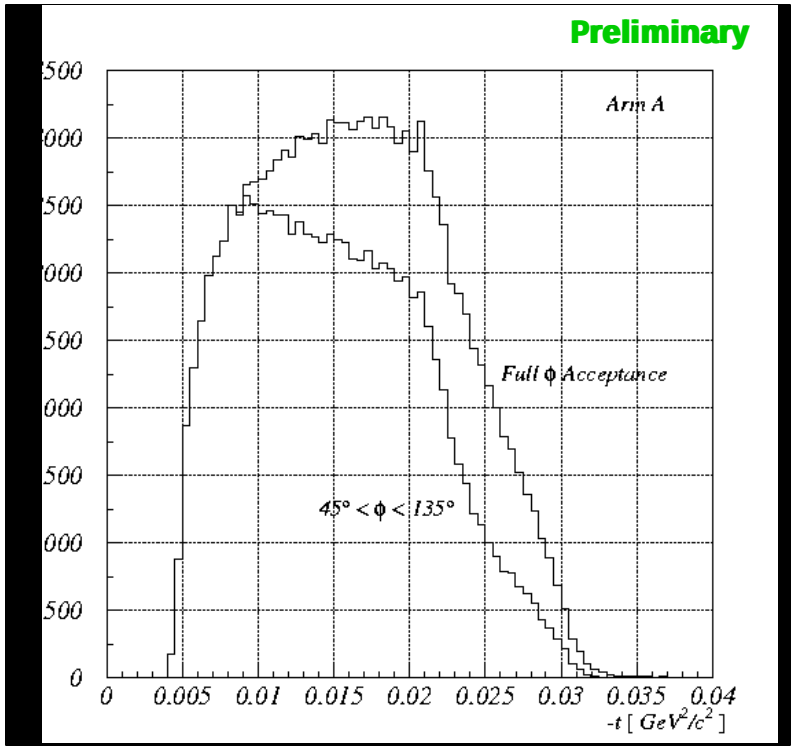
Expected Results of 2002 Data Analysis

Extraction of diffraction cone slope b

Calculation of single spin asymmetry A_N

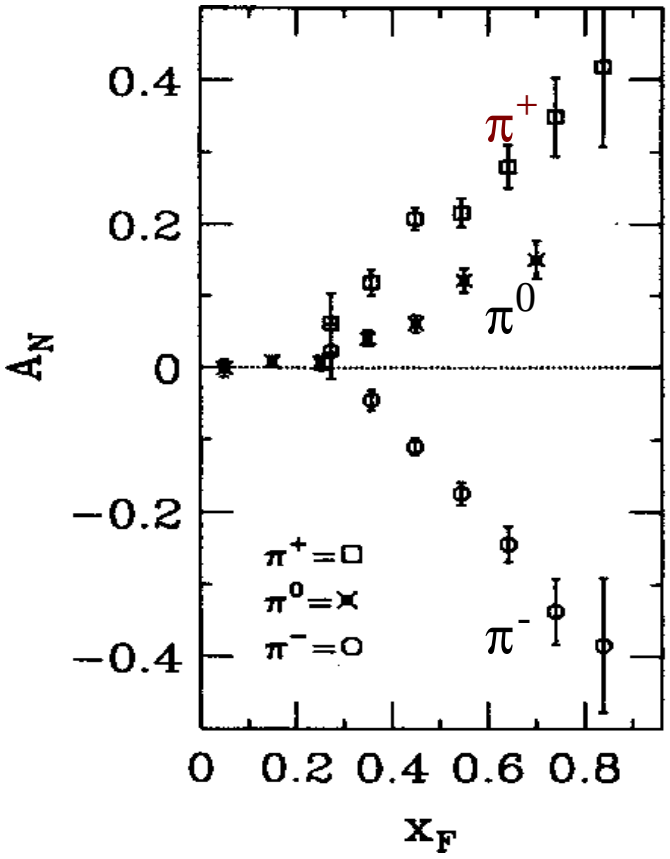
Preliminary |*t* |-distribution for elastically scattered protons with

- **for all azimuthal angles and**
- **for a limited range of azimuth, resulting in full acceptance in 0.010 GeV^2 < |*t* | < 0.019 GeV^2, we obtain from fit b = (16.4 ±1.6) GeV^{-2}**



Spin asymmetries in π^0 production: $p_{\uparrow} + p \rightarrow \pi + X$

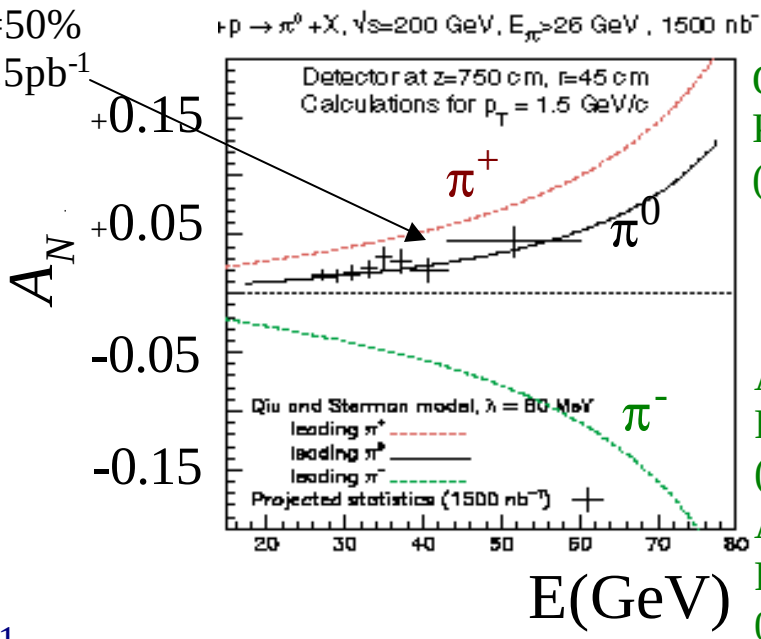
Non-zero A_N measured in E704 at Fermilab at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:



[0] - D.L. Adams, et al., Phys. Lett. B261(1991)201.
[+/-] - D.L. Adams, et al., Phys. Lett. B264(1991)462.

Predictions by different theorists expect non-zero A_N values, attributed to different dynamics, to persist at RHIC energies: $\sqrt{s}$=200 GeV...

Simulation w/P_b=50% and 1.5pb^{-1}



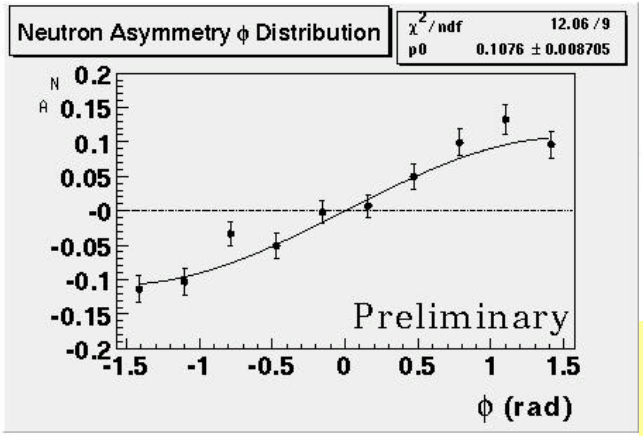
Qiu and Sterman, Phys. Rev. D59 (1998) 014004.

See also:

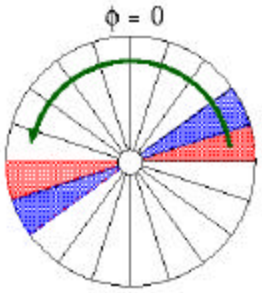
Anselmino, et al., Phys. Lett. B442 (1998) 470.;
Anselmino, et al., PRD 60 (1999) 054027.

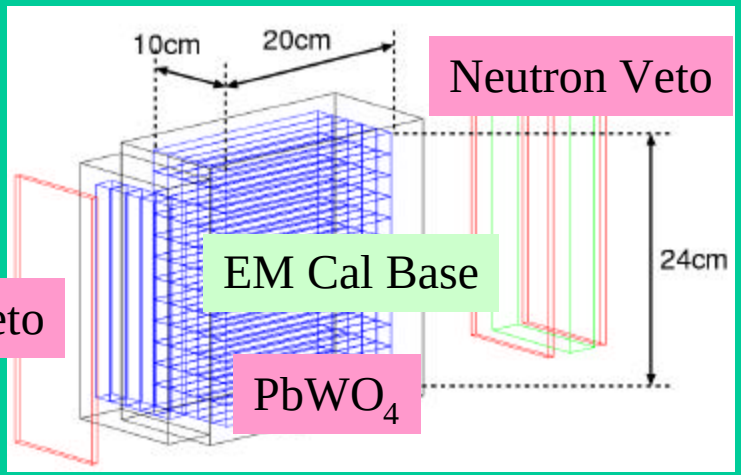
...Non-zero analyzing power expected to persist up to RHIC collision energies...

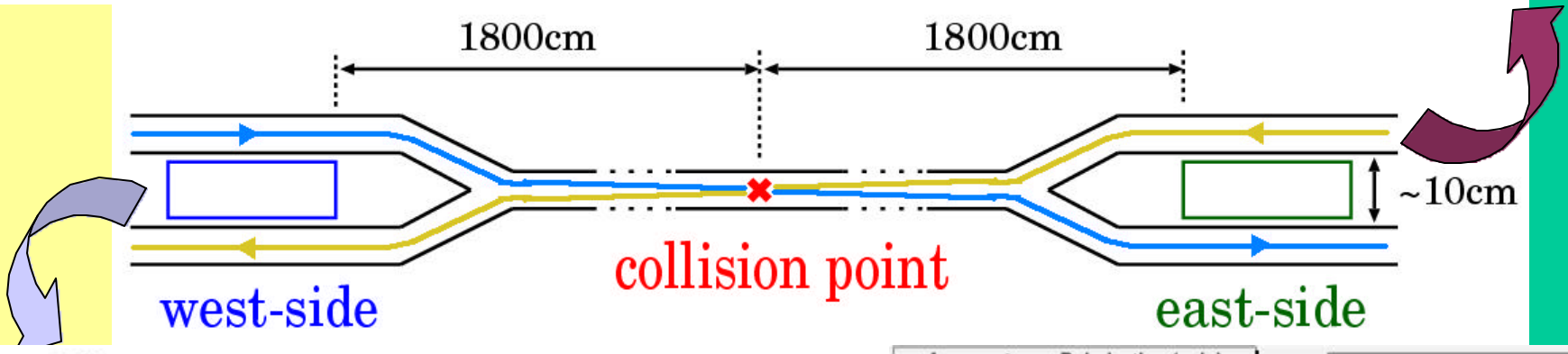
G. Rakness (IUCF)
SPIN 2002

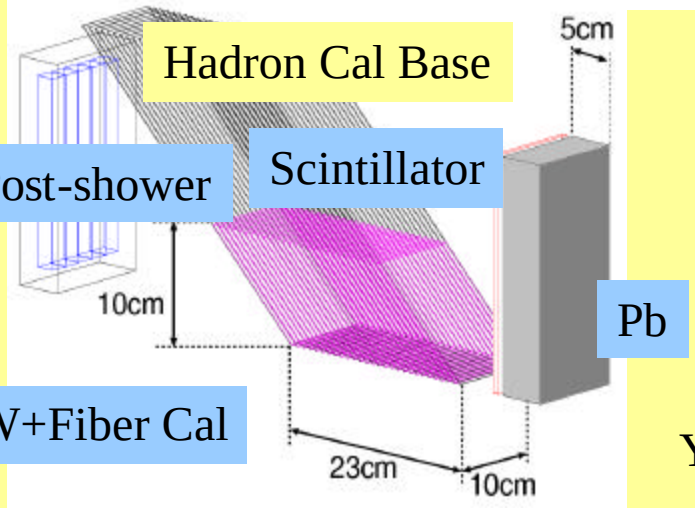


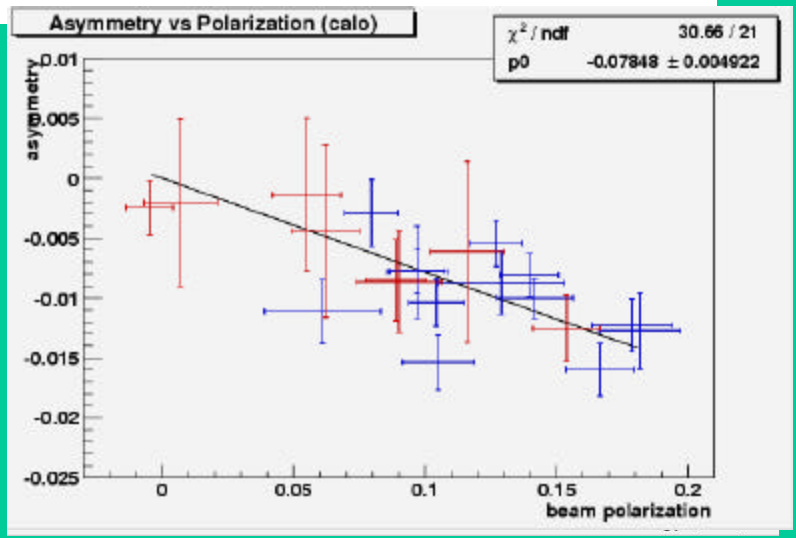
$\langle A_N \rangle = -0.108 \pm 0.0087$











Y. Fukao (Kyoto)
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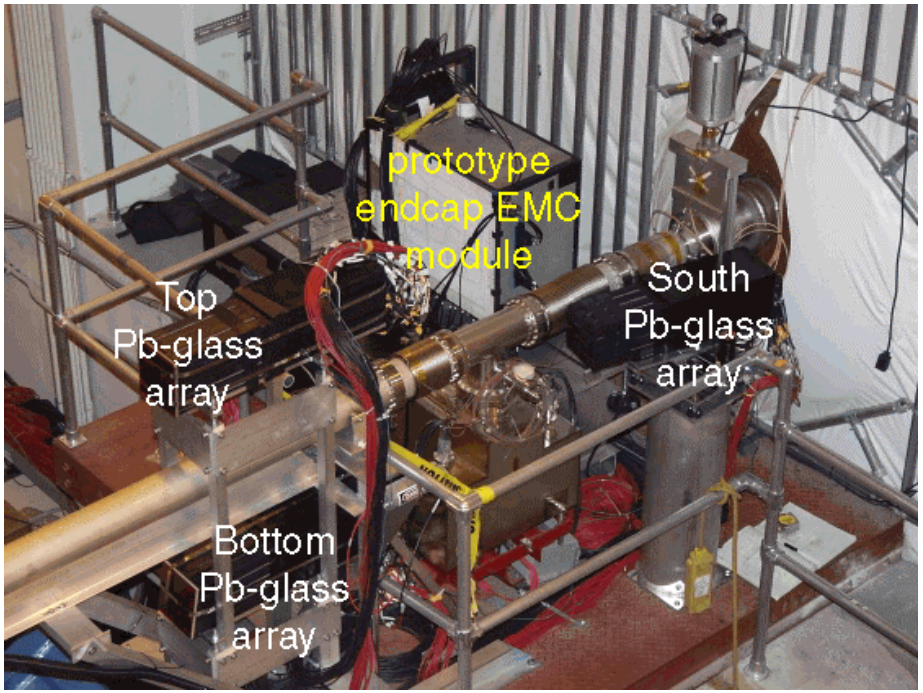
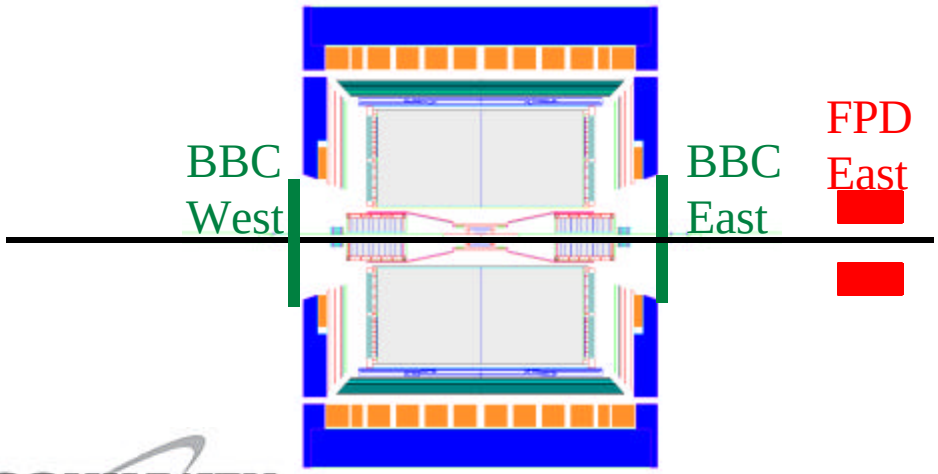
Prototype Forward π^0 Detector (FPD) at STAR

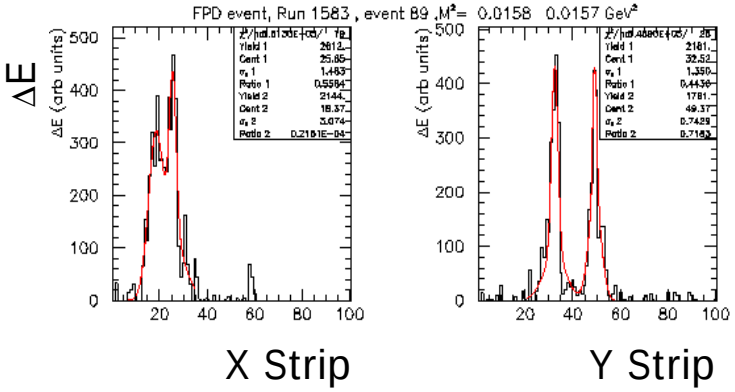
Located east of STAR detector at z=750cm:



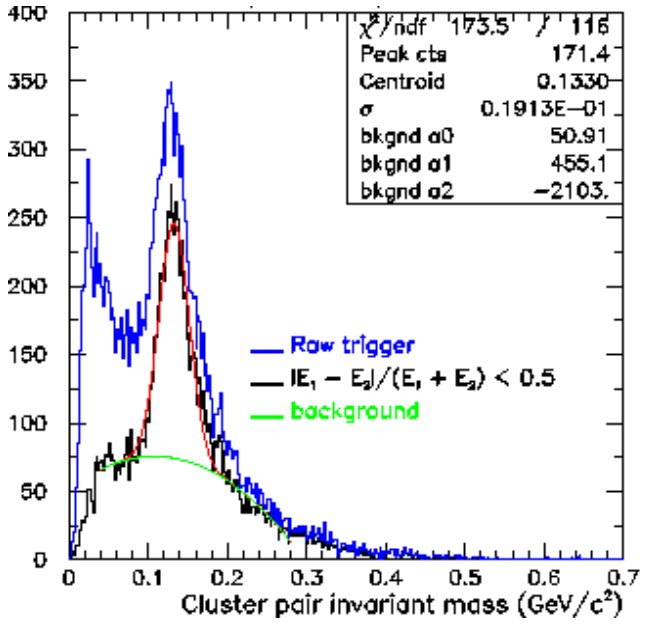


- Pb-glass detectors provided by IHEP-Protvino
- prototype STAR Endcap EMC module

Single event analysis sees $\pi^0 \rightarrow \gamma\gamma$:



Identified particles up to >60 GeV



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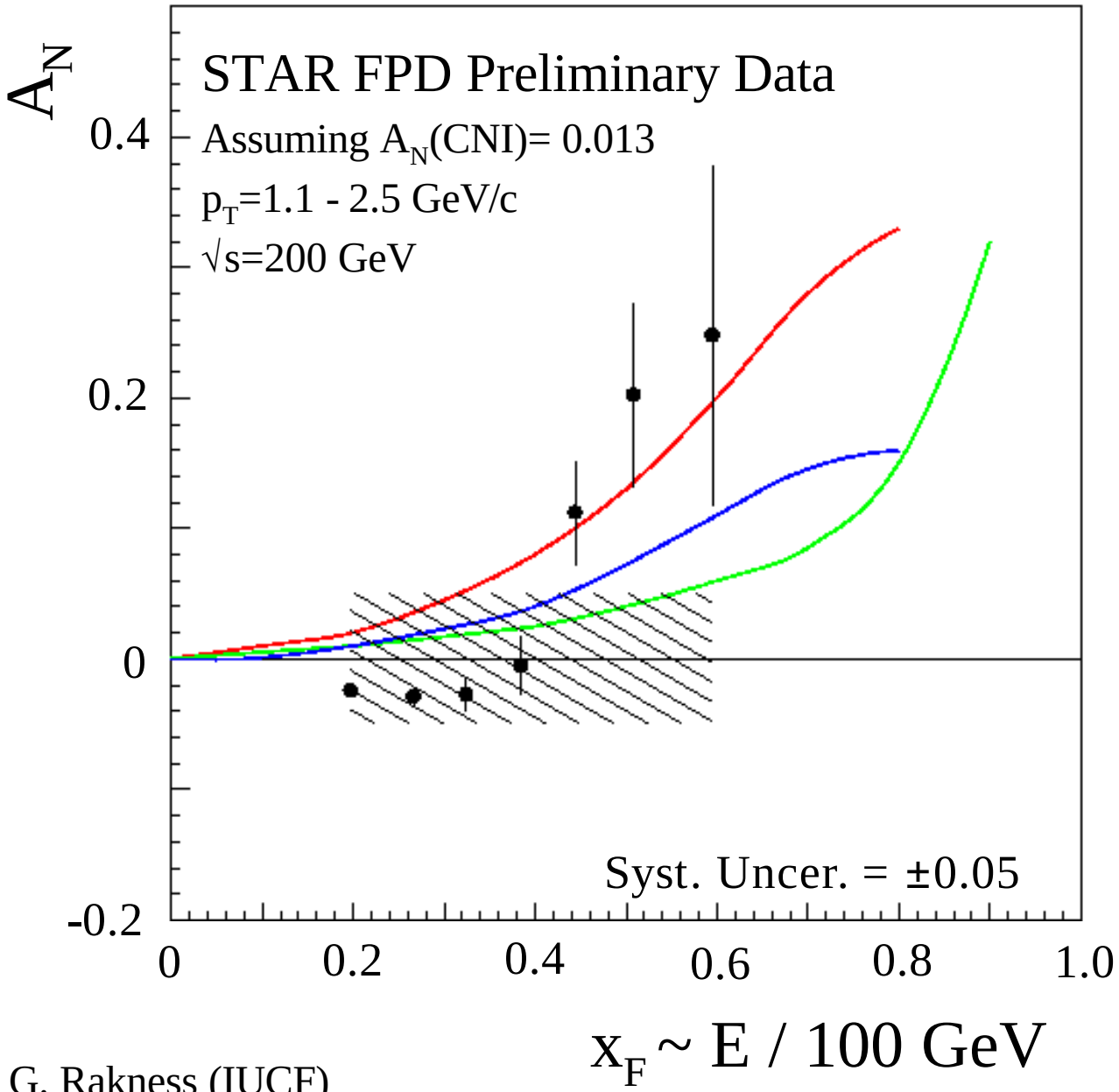
$p_{\uparrow} + p \rightarrow \pi^0 + X$



Theory predictions at p_T=1.5 GeV/c:

Collins effect
Anselmino, et al., private communication;
PRD 60 (1999) 054027.

Sivers effect
Anselmino, et al., private communication;
Phys. Lett. B442 (1998) 470.

Twist 3 effect
Qiu and Sterman, private communication;
PRD 59 (1998) 014004.

G. Rakness (IUCF)
SPIN 2002

STAR spin

RHIC Run 3 Goals...

8 weeks of polarized proton running

- Continue commissioning of RHIC for spin.

Goal: $\mathcal{L}=10^{31}$ cm^{-2}s^{-1} , $P_{beam}=0.4$

- Confirm tuning of spin rotator magnets via absence of left/right and up/down spin asymmetries.
- Improve precision of A_N measurements for forward π production.
- A_{LL} for mid-rapidity inclusive jet (STAR) and hadron (PHENIX) production as a probe gluon polarization.

…and beyond

- Polarized gas jet target for CNI polarimeter calibration (Run 4)
- $\sqrt{s}$=500 GeV commissioning and first run (Run 4)
- Warm helical partial Siberian Snake in AGS (RIKEN / Run 4)
- Strong Siberian Snake in AGS for improved polarization (Run 5)
- Improved luminosity for γ and W physics

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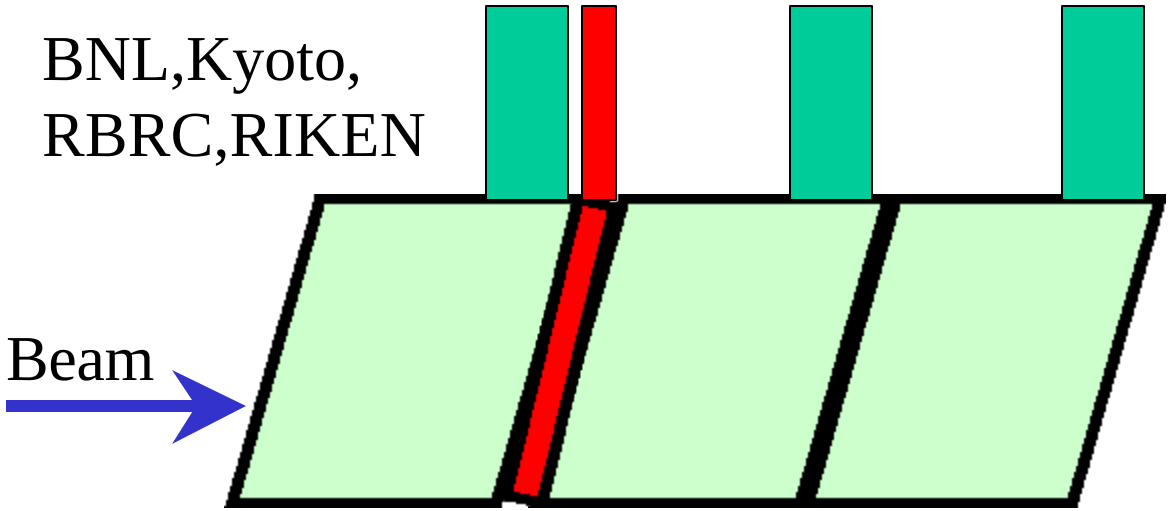
Shower Max Detector + Zero Degree Calorimeter

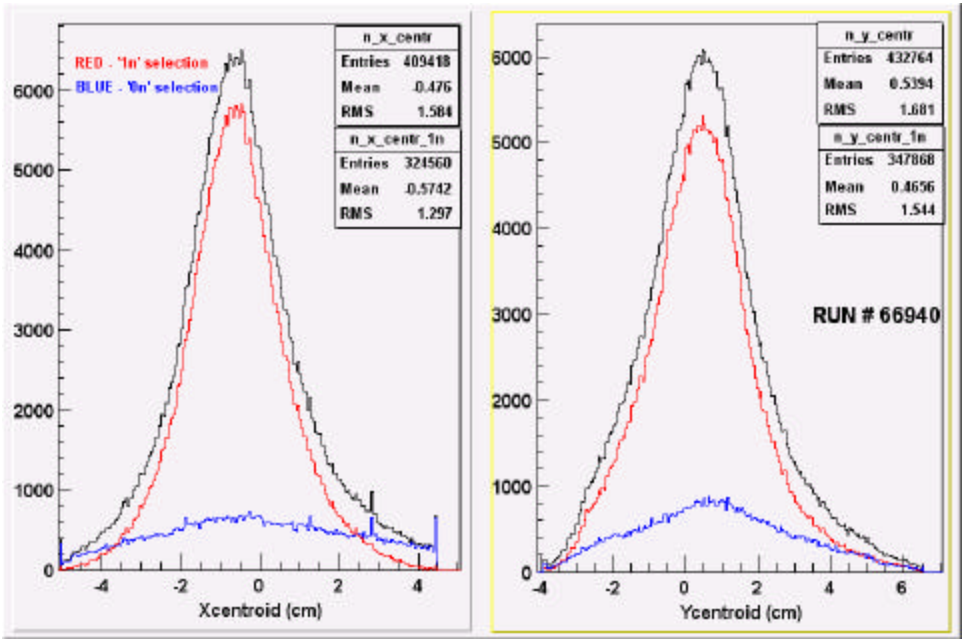
PHENIX Local Polarimeter Run 3

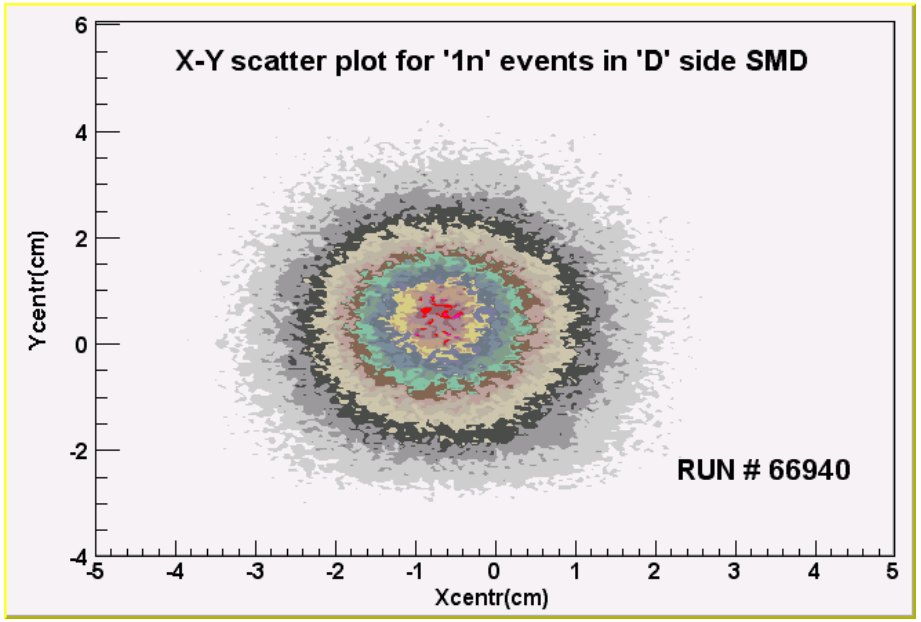
BNL,Kyoto,
RBRC,RIKEN



SMD:8 vertical
7 horizontal
Strips cover
The sensitive
front face of ZDC

Deuteron-Gold Run (PRELIMINARY)





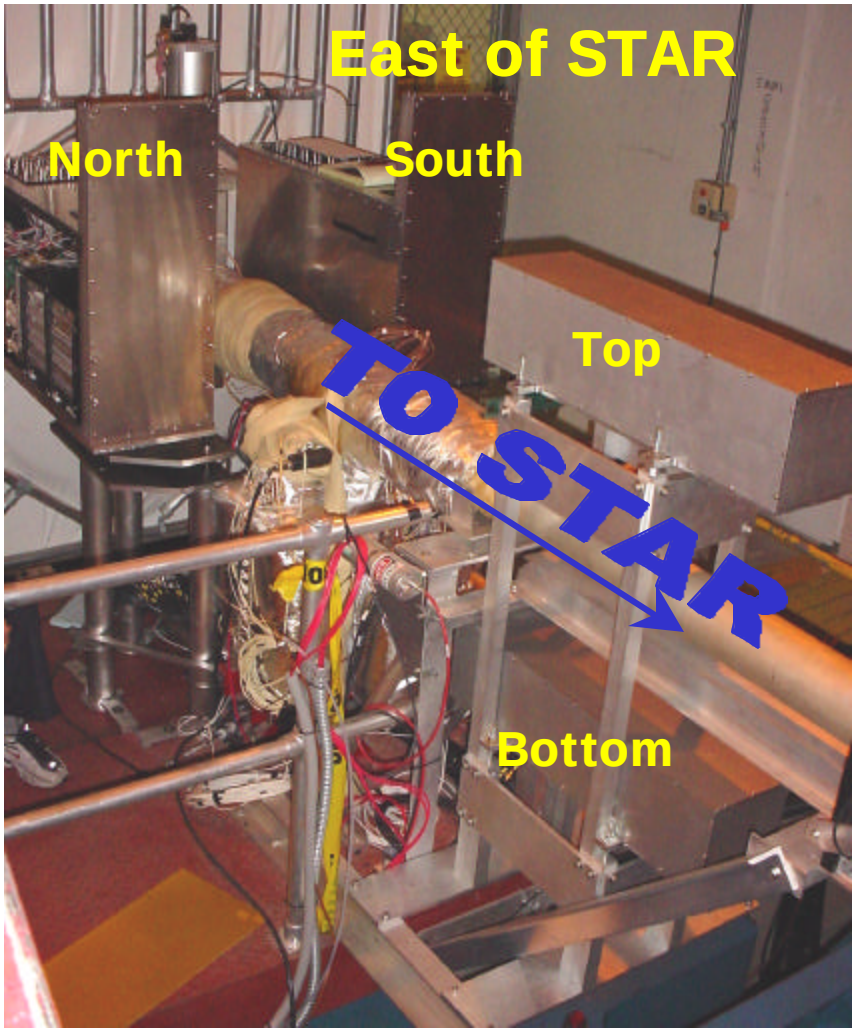
STAR Forward Pion Detector

Run 3 Objectives:

- probe of Color Glass Condensate in d+Au
  $\Rightarrow$ p_T dependence of large η yield
- improve understanding of dynamical origin of A_N in $p_\uparrow$+p
- tune spin rotator magnets (local polarimeter)

Status:

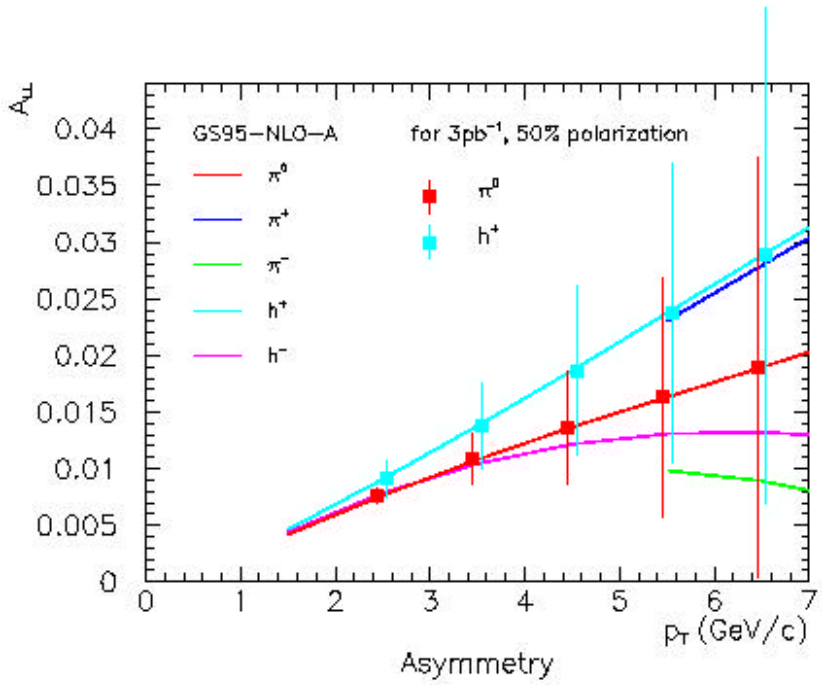
- all Pb-glass+shower max. detectors installed on east
- half of planned detectors installed on west
- Pb-glass readout commissioning underway
- Shower max. readout installation during 3/12 access

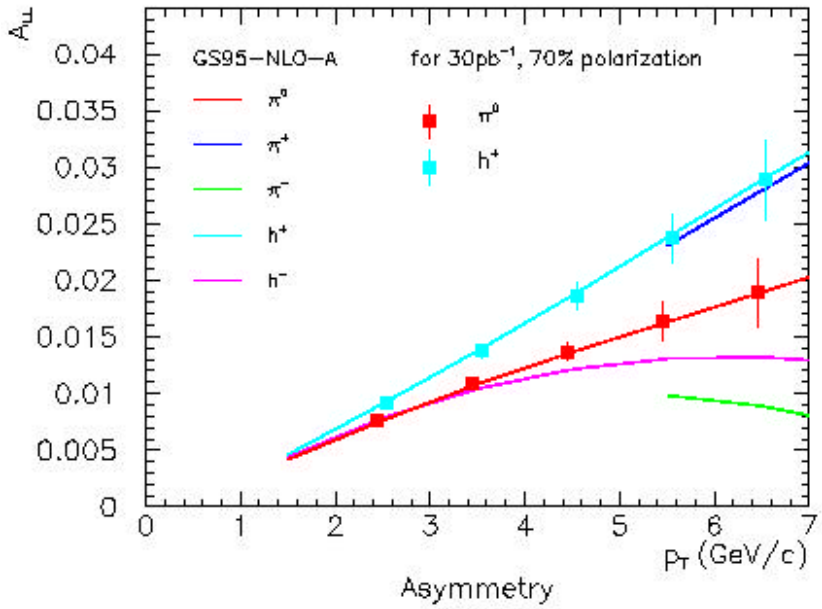


BNL, Penn State, IHEP-Protvino,
UC Berkeley/SSL, UCLA, ANL

Pion/Hadron A_{LL} Measurement

- Run-3
  - –by assuming
    - $3pb^{-1}$
    - 50% polarization
- Run-4
  - –by assuming
    - $30pb^{-1}$
    - 70% polarization

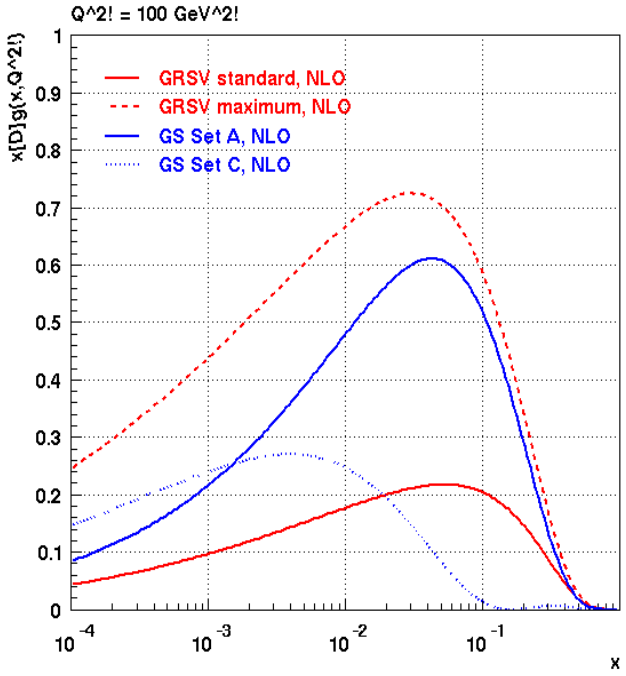


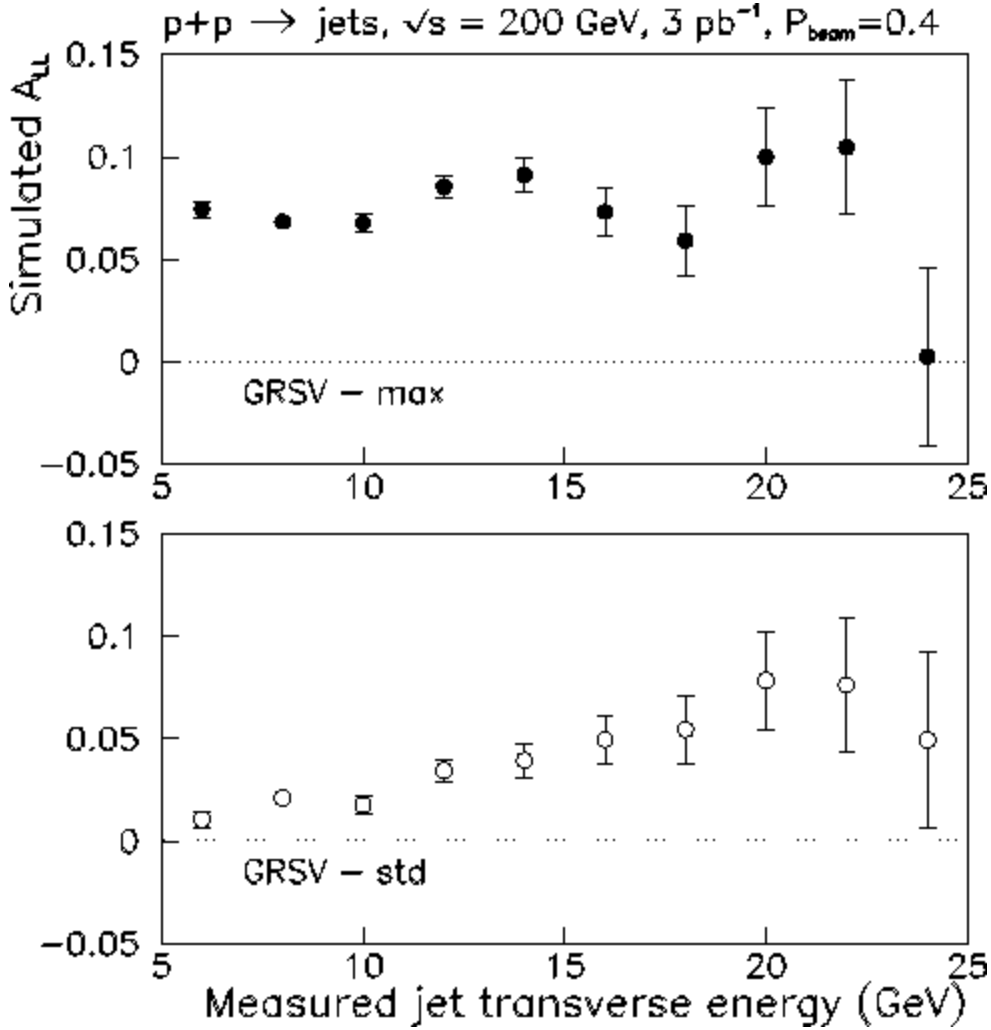


Y. Goto, RIKEN/RBRC
SPIN 2002

Inclusive jet production

- Luminosity: 3 pb^{-1}
- √s = 200 GeV
- Polarization: 0.4
- Assume: Coverage of EMC (barrel) 0 < Ö < 2ð and 0 < ç < 1
- Jet Trigger: E_T > 5 GeV over at least one "patch" (Äç = 1) X (ÄÖ = 1)
- Jet reconstruction: Cone algorithm (seed = 1 GeV, R = 0.7)





Clear sensitivity in A_{LL} for inclusive jets between ÄG of GRSV-max and GRSV-std!

B. Surrow (BNL)
SPIN 2002

PP2PP Summary

- **pp2pp will measure spin-dependent elastic proton-proton scattering in a new kinematic region;**
- **pp2pp will probe the Pomeron (Odderon): Large distance QCD;**
- **First engineering run was very successful:**
  - **Working on first physics results: nuclear slope B at $\sqrt{s}$ = 200**
  - **Possibly A_N**
- **Next: finish building experiment and complete physics program**
- **Exciting opportunities at RHIC for pp2pp over the next few years**

2003 – at $\sqrt{s}$ = 200 GeV: σ_{tot}, **B,** $d\sigma/dt$, $A_N(t)$, $A_{NN}(t)$

2004 – at $\sqrt{s}$ = 500 GeV: σ_{tot}, **B,** $d\sigma/dt$, $A_N(t)$, $A_{NN}(t)$

$\Delta\sigma_{tot} \sim 3\%$, $\Delta A_N \approx 0.2\text{-}0.3\%$ ($A_N \sim 4\%$)

2005 – at $\sqrt{s}$ = 500 GeV: $B(t)$, $d\sigma/dt$, diffractive minimum

Summary

- RHIC will provide a new generation of proton spin structure studies
    - o gluon contribution to the proton's spin
    - o spin/flavor decomposition of the sea
- First polarized proton collisions at $\sqrt{s}$=200 GeV during RHIC run 2 $\Rightarrow$ transverse single spin asymmetries.
- Plans for further A_N measurements and first A_{LL} measurements of inclusive hadrons and jets in RHIC run 3.

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